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Computer program for ultimate strength analysis of ship hulls subjected to moment, TORQUE AND SHEAR, November 1982. (NTIS MA-RD-94082981)

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To F.L.

MAXIMUM STRENGTH OF SHIP HULLS

COMPUTER PROGRAM FOR ULTIMATE STRENGTH ANALYSIS OF SHIP HULLS SUBJECTED TO MOMENT, TORQUE AND SHEAR

BY

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This report describes a computer program for the determination of the behavior and ultimate strength of longitudinally stiffened ship hull girders of single-cell cross section subjected to moment, shear and torque. The logic of the program and of its subroutines is presented. The compression flange is assumed to behave as if it was composed of independent beam-columns whose axial load vs. deformation relationship is established by another computer program. Axial response of the remainder of the section up to the buckling or yielding stress is assumed to be of a bi-linear, elastic-plastic pattern. After buckling, the shear response of the girder webs is considered to be according to the multiple tension-field theory. This program can maintain plane section or accommodate any degree of warping as specified by the user. The input for the program consists of the geometrical and material properties of the girder segment, and of the relative values of the forces applied to the cross section: moment, shear and torque. The output gives the curvature of the girder segment and the corresponding load parameter which is related to the bending moment, shear and torque acting on the cross section. All the principal variables and the formats of the input and output are defined. However, the actual listing of the program is not included in the report; it is available upon request.

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Longitudinal Stability
Buckling
Torsion

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COMPUTER PROGRAM
FOR
ULTIMATE STRENGTH ANALYSIS OF SHIP HULLS
SUBJECTED TO MOMENT, TORQUE AND SHEAR

by
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ABSTRACT

This report describes a computer program for the determination of the behavior and ultimate strength of longitudinally stiffened ship hull girders of single-cell cross section subjected to moment, shear and torque. The logic of the program and of its subroutines is presented.

The compression flange is assumed to behave as if it was composed of independent beam-columns whose axial load vs. deformation relationship is established by another computer program. Axial response of the remainder of the section up to the buckling or yielding stress is assumed to be of a bi-linear, elastic-plastic pattern. After buckling, the shear response of the girder webs is considered to be according to the multiple tension-field theory. This program can maintain plane section or accommodate any degree of warping as specified by the user.

The input for the program consists of the geometrical and material properties of the girder segment, and of the relative values of the forces applied to the cross section: moment, shear and torque. The output gives the curvature of the girder segment and the corresponding load parameter which is related to the bending moment, shear and torque acting on the cross section.

All the principal variables and the formats of the input and output are defined. However, the actual listing of the program is not included in the report; it is available upon request.

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1. INTRODUCTION

The computer program described in this report was developed for analyzing single-cell rectangular ship hull sections, symmetrical about the vertical centroidal axis and loaded by a combination of moment, shear and torque. The theoretical basis for this program is described in Reference [1], and only a brief summary of the principal features of the theory are given here.

The longitudinally stiffened segment of the girder between two transverses consists of two sides (webs) and the tension and compression flanges, as shown in Fig.1. Behavior of each of these components is assumed to follow a different pattern consistent with its expected response.

Longitudinal stiffeners of the web and of the tension flange are assumed to be perfectly elastic-plastic. The tension flange plate is assumed to be bi-linearly elastic-plastic with the yielding limit determined under the combination of tensile and shearing stresses. The compression flange is treated as if it consisted of independent beam-columns, each composed of a longitudinal stiffener and a portion of the plate with a width equal to the spacing of the stiffeners. The pre- and post-ultimate load-deformation relationship for a compression flange stiffener beam-column is obtained by using another computer program. (Three different programs have been employed for this purpose: [2] - [3], [4].) The webs are analyzed under the combined effects of normal and shearing stressess. Each web plate subpanel is assumed to be perfectly elastic until it either yields or buckles. After buckling, a subpanel can carry only additional shear by means of tension-field action (normal stresses remain at the buckling level) [3].

The program can accommodate any degree of warping or can assume that a plane section remains plane. The degree of warping is specified as a constant percentage of deplanation (see Fig.2).

2. DESCRIPTION OF PROGRAM

2.1 Basic Procedure

The program calculates the load parameter for successive values of curvature. The deformational input consists of the initial and final values and of the increment of curvature.

The computational procedure is as follows: For a given value of curvature, the strains at the four corners are calculated using an iterative process which forces the resultant axial force and the bending moment about the vertical centroidal axis to become equal to zero, hence, enforcing equilibrium of the cross section. The strains are assumed to vary linearly on each side from corner to corner and the cross section is enforced to remain plane or to have the prescribed degree of warping. After the equilibrium of the cross section is achieved for the given value of curvature, bending moment about the horizontal axis (M) is calculated. Since the bending moment, shear, and torque are each related to the load parameter (W) by a constant coefficient, the values of transverse shear (V) and torsion (T) are then computed.

W = M/AMU2

then, V = W*AMU1

and T = W*AMU3

where AMU1, AMU2, and AMU3 are the relevant constants.

Shearing stresses due to transverse shear and St. Venant torsion are computed for each web subpanel. The buckling interaction value, given by the buckling interaction equation, is then checked for each web subpanel to see if it has buckled.

If a subpanel has buckled, the curvature is decreased and iteration is performed to get to the theoretical buckling state of that subpanel before the value of curvature is incremented again. After buckling, a web subpanel is assumed to carry no additional normal or bending stresses beyond those present at buckling. However, the web subpanel can carry additional shearing stress by tension-field action.

If the subpanel has not yet buckled, it is still behaving elastically. Then, the calculated load parameter represents one state of load response of the hull girder for the given value of curvature. Repeated curvature input produces an array of load parameters for the hull girder from zero to the ultimate load.

In the post-ultimate range, where the load parameter decreases with the increasing curvature, the corresponding decrease in shear and torsion causes reduction of shearing stresses in the web subpanels. Elastic unloading is assumed to take place in this range.

2.2 Assumptions

The principal assumptions of the method are the following:

1. The box girder segment is straight and prismatic, the cross section is single-cell and symmetrical about the vertical centroidal axis.
2. The strain varies linearly from corner to corner.
3. After a web subpanel has buckled, the normal and bending stresses are assumed to remain constant at the buckling level.
4. For each web subpanel the shear stress-strain relationship is assumed to be segmentally linear, as defined by the points at zero, buckling, and ultimate stress values. After the ultimate capacity is reached, the shear strain increases at the same level of stress.
5. Gross residual stresses in the box girder section are not considered. The effect of residual stresses on the behavior of the compression flange is incorporated into the axial load vs. deformation relationship by the other programs which are used to compute the behavior of the compression flange.
6. Shear strains due to warping are very small.
7. The effect of shear lag is assumed to be negligible.

2.3 Components of Computer Program

The program consists of the main program and nine subroutines (see the flowchart in Fig.3). The function of each subprogram is described as follows:

1. Main program BOX reads and prints the input data.

2. Subroutine WVSDEF is the main control subroutine. It determines three initial sets of the values of the axial force and of the moment about the vertical axis for three different sets of corner strains (see Item 4 - subroutine TWOPLA). The strains are then iterated until convergence criteria are met. This subroutine checks the interaction values of the web subpanels to see which ones may have buckled, and when necessary, it uses linear interpolation to reduce the curvature to put the subpanel in question at the buckling level. Also, subroutine WVSDEF iterates, with the aid of subroutine PARMAX, to pinpoint the ultimate strength of the girder.
3. Subroutine CRISTR calculates the pure buckling stresses for each web subpanel (bending, normal, and shearing).
4. Subroutine TWOPLA is called by subroutine WVSDEF to obtain the next best values of the variable corner strains S1 and S2 to make the axial force and the bending moment about the vertical centroidal axis equal to zero. Each function (axial force and moment) is represented by a plane defined by three points. The point where the intersection line between these two planes has a zero value for both of the functions gives the next approximation to S1 and S2.
5. Subroutine WEBSH decides how much shearing stress is carried by each web subpanel and calculates the buckling interaction value for each subpanel. Also, the shear mode of failure, if it occurs, is detected in this subroutine.
6. Subroutine AFAYM is given the strain at each of the four corners

of the hull girder and it calculates the resultant axial force and the resultant bending moment about the vertical centroidal axis.

7. Subroutine PROPRT calculates most of the quantities which need to be calculated only once.
8. Subroutine MOMENT calculates the bending moment (M) about the horizontal axis of the section.
9. Subroutine PARINT uses parabolic interpolation to find the "Y" value corresponding to the given "X" value from three given points.
10. Subroutine PARMAX is given the coordinates of three points and it finds argument "X" for the maximum value of function "Y" by using parabolic curve fitting and differentiation.

2.4 Code

This program is written in ANSI Fortran IV (1977).

2.5 Core Requirements

The core requirement is approximately 42,200 60-bit bytes.

2.6 Availability of Program Listing

The code listing of the program is available upon request from:

A. Ostapenko, Fritz Engineering Laboratory, Bldg 13,
Lehigh University, Bethlehem, Pa. 18015, USA.

3. RESTRICTIONS

3.1 Limitations For Use

The arrays used by this program have fixed dimensions which impose the following limitations:

1. Storage space has been provided for a maximum of 50 values of curvature and the corresponding load parameter. To raise this limitation, the dimensions of the following arrays must be increased to at least the desired number of values:

CURV	STRA2
SHEAR1	STRA3
SHEAR2	STRA4
STRA1	WLO

2. The number of points describing the axial load response of a compression flange stiffener beam-column (NPC) is limited to a maximum of 100. To raise this limitation, the dimensions of arrays EPPLC and PCOMP should be increased to at least the desired value of NPC.
3. The number of compression flange stiffeners (NC) is limited to a maximum of 20. To raise this limitation, the dimension of array FORCE must be increased to at least the desired value of NC.
4. The number of tension flange stiffeners (NT) is limited to a maximum of 20. To raise this limitation, the dimensions of arrays FORTE and FORTEF must be increased to at least the desired value of NT.
5. The number of web subpanels in each web (NW) is limited to a max-

imum of 18. To raise this limitation, the following dimensions must be increased.

a. The dimensions of arrays STRNW1 and STRNW2 must be increased, at least, to NW+2.

b. The dimension of array WINSAV must be increased, at least, to NW*2.

c. The dimensions of the following arrays must be increased to at least the desired value of NW:

ALPHA	IST01B	SUB2V
ASTW	IST02B	V1
DEP	IULT1	V2
FBCR	IULT2	V1ULT
FCCR	SAV1B	V2ULT
FVCR	SAV2B	VMAX1
GAMUL1	SAVSH1	VMAX2
GAMUL2	SAVSH2	W1FOR
GBUCK1	SUB1B	W2FOR
GBUCK2	SUB2B	WIN1A
GE1	SUB1F	WIN2A
GE2	SUB2F	WIN1B
IBUCK1	SUB1SB	WIN2B
IBUCK2	SUB2SB	WINTR1
IST01A	SUB1V	WINTR2
IST02A		

3.2 Nonstandard Hardware and Tapes

None.

3.3 Array Dimensions

The arrays used in the program and their dimensions are listed below.

ALPHA(18)	GE2(18)	SHEAR1(50)	V1ULT(18)
ASTW(18)	IBUCK1(18)	SHEAR2(50)	V2ULT(18)
AXF(3)	IBUCK2(18)	STRA1(50)	VMAX1(18)
CURV(50)	IST01A(18)	STRA2(50)	VMAX2(18)
D(20)	IST02A(18)	STRA3(50)	W1FOR(18)
DEP(18)	IST01B(18)	STRA4(50)	W2FOR(18)
EPPLC(100)	IST02B(18)	STRNW1(20)	WIN1A(18)
FBCR(18)	IULT1(18)	STRNW2(20)	WIN2A(18)
FCCR(18)	IULT2(18)	SUB1B(18)	WIN1B(18)
FORCE(20)	PCOMP(100)	SUB2B(18)	WIN2B(18)
FORTE(20)	S1(3)	SUB1F(18)	WINSAV(36)
FORTEF(20)	S2(3)	SUB2F(18)	WINTR1(18)
FVCR(18)	S3(3)	SUB1SB(18)	WINTR2(18)
GAMUL1(18)	S4(3)	SUB2SB(18)	WLO(50)
GAMUL2(18)	SAV1B(18)	SUB1V(18)	YBMO(3)
GBUCK1(18)	SAV2B(18)	SUB2V(18)	YS1(3)
GBUCK2(18)	SAVSH1(18)	V1(18)	YS2(3)
GE1(18)	SAVSH2(18)	V2(18)	

4. DATA PREPARATION

4.1 Card Input Form

For the definition of the variables, see the Symbol list in Section 4.3 and Fig.4.

Card No.	Format	Variable Name	Comment
1.	14A5,I5,F5.0		Specimen identification - up to 70 characters.
		IFLAG	Blank or zero - abbreviated output; Nonzero - detailed output.
		SWP	Degree of warping; Blank or zero - plane section is enforced; Otherwise - the specified amount of warping is maintained (see Fig.2).
2.	16I5	NC	Number of longitudinal stiffeners in the compression flange.
		NT	Number of longitudinal stiffeners in the tension flange.
		NW	Number of subpanels in one web.
		NPC	Number of points which define the axial load vs. deformation response of a stiffener beam-column in the compression flange.
		NDIR	-1 if the longitudinal stiffeners on the flanges are on the outside of the girder; 1 if the stiffeners are on the inside of the girder.
3.	8F10.0	AA	Length of the segment; it is equal to the distance between transverse stiffeners or bulkheads.
		B	Width of the box girder cross section (center to center of web plates).
		TC	Thickness of the compression flange plate.
		DC	Distance between the mid-thickness of the compression flange plate and the centroid of the compression flange stiffener.
		AFLSTC	Area of the compression flange stiffener.

		TT	Thickness of the tension flange plate.
		DT	Distance between the mid-thickness of the tension flange plate and the centroid of the tension flange stiffener.
		AFLSTT	Area of the tension flange stiffener.
4.	8F10.0	TW	Thickness of the web plate.
		D	Array consisting of the distances from the mid-thickness of the compression flange plate to the web stiffeners and to the tension flange plate (starting at the compression flange and proceeding towards the tension flange). This array contains NW+1 elements. NOTE: D(NW+1)= the center to center distance between the tension and compression flange plates. More than one card may be required.
5.	8F10.0	ASTW	Array consisting of the areas of the web stiffeners (starting at the compression flange and proceeding towards the tension flange). This array contains NW-1 elements. More than one card may be required.
6 .	8F10.0	PCOMP	Array of normalized stresses describing the behavior of the compression flange stiffener beam-column (the average stress divided by the yield stress of the compression flange plate). This array contains NPC elements (the first element must be zero). More than one card may be required.
7.	8F10.0	EPPLC	Array of normalized strains describing the axial load response of the compression flange stiffener beam-column (the edge strain divided by the yield strain of compression flange plate). This array contains NPC elements (the first element must be zero). More than one card may be required.
8.	3F10.0	AMU1	Coefficient that relates shear force in the section to the load parameter (AMU1=V/W).
		AMU2	Coefficient (units of length) that relates moment in the section to the load parameter (AMU2=M/W).
		AMU3	Coefficient (units of length) that relates torsion in the section to the load parameter (AMU3=T/W).
9.	6F10.0	EL	Modulus of ELasticity.
		POISSO	Poisson's ratio.
		SIGYC	Yield stress of the compression flange plate.

		SIGYT	Yield stress of the tension flange plate.
		SIGYST	Yield stress of the stiffeners of the webs and tension flange.
		SIGYWB	Yield stress of the web plate.
10.	3F10.0	CE	Initial value of curvature.
		CEINC	Increment of curvature.
		CEMAX	Maximum curvature at which program should stop.

4.2 Description of Output Form

4.2.1 Brief Output Form

1. All input data is printed for checking.

2. Each value of curvature is printed along with the corresponding load parameter and corner strains.

3. A warning message will appear if the convergence criteria are not met for a particular value of curvature.

4. In the event of a shear failure, the appropriate message is printed.

4.2.2 Detailed Output Form

In addition to the information provided by the brief output form, the detailed output form provides enough information for the user to follow the computational logic of the program (see EXAMPLE).

4.3 Definition of Principal Symbols

AA	Length of the segment; it is equal to the distance between transverse stiffeners or bulkheads.
ACFE	Area of compression flange beam-column, composed of a longitudinal stiffener and a portion of compression flange plate with width equal to spacing of adjacent longitudinal stiffeners.
AFLSTC	Area of a compression flange stiffener.
AFLSTT	Area of a tension flange stiffener.
ALPHA	Array of aspect ratios of individual web subpanels.
ALPMN	Smallest value in array ALPHA.
AMUI	Coefficient which relates shear force in section to the load parameter.
AMU2	Coefficient which relates moment in section to the load parameter.
AMU3	Coefficient which relates torsion in section to the load parameter.
ASTW	Array of the areas of web stiffeners.
AXF	Array of three resultant axial forces which correspond to three sets of strains.
AXFY	Approximate value of axial force which causes yielding in section.
B	Width of the section (center to center of web plates).
BSUBV1	Value of shear force carried by bottom subpanel of Web 1.
BSUBV2	Value of shear force carried by bottom subpanel of Web 2.
CE	Value of curvature.
CEINC	Increment of curvature.
CEMAX	Value of curvature at which program should stop.
CORN	Area of a portion of compression flange plate with a width equal to one-half the distance from a corner to the adjacent compression flange stiffener.
CURV	Array of curvatures for which the proper load response has

been found.

D Array of distances from the mid-thickness of compression flange plate to the web stiffeners and to the mid-thickness of the tension flange plate.

DC Distance between mid-thickness of compression flange plate and centroid of a compression flange stiffener.

DCS Distance between the mid-thickness of compression flange plate and centroid of a compression flange beam-column.

DCST Distance between mid-thickness of tension flange plate and centroid of a compression flange stiffener beam-column.

DEP Array of depths of individual web subpanels.

DT Distance between mid-thickness of tension flange plate and centroid of a tension flange stiffener.

EL Modulus of elasticity.

EPPLC Array of normalized strains describing axial load response of a stiffener beam-column of compression flange (overall strain divided by yield strain of compression flange plate). In computations within the program, the values are transformed back to the overall strains.

FACMAG Approximate section modulus about vertical centroidal axis, divided by cross-sectional area of girder. Values of moment about vertical axis are divided by FACMAG so that these moments and the axial forces are of approximately the same order of magnitude. This procedure increases the efficiency of subroutine TWOPLA.

FBCR Array of pure critical bending moments for web subpanels.

FCCR Array of pure critical normal forces for web subpanels.

FCORN1 Force in section of compression flange plate which is bounded by Web 1 and mid-point to the nearest stiffener.

FCORN2 Force in section of compression flange plate which is bounded by Web 2 and mid-point to the nearest stiffener.

FORCE Array of axial forces of stiffener beam-columns.

FORTE Array of axial force of tension flange stiffeners.

FORTEF Array of axial forces of tension flange elements. A tension flange element is composed of a portion of tension flange plate having width equal to spacing of adjacent tension flange stiffeners.

FVCR	Array composed of pure critical shearing forces of web subpanels.
G	Shear modulus.
GAM1	Shear strain in Web 1 during post-ultimate behavior.
GAM2	Shear strain in Web 2 during post-ultimate behavior.
GAMMA1	Shear strain in Web 1 during pre-ultimate behavior.
GAMMA2	Shear strain in Web 2 during pre-ultimate behavior.
GAMUL1	Array of shear strains at which ultimate shear strengths of individual subpanels in Web 1 are reached.
GAMUL2	Array of shear strains at which ultimate shear strengths of individual subpanels in Web 2 are reached.
GBUCK1	Array of shear strains of subpanels in Web 1 at which buckling occurs.
GBUCK2	Array of shear strains of subpanels in Web 2 at which buckling occurs.
GE1	Array of effective shear moduli of subpanels in Web 1. The effective shear modulus is the slope of the shear stress-strain diagram between the buckling point and the ultimate shear strength.
GE2	Array of effective shear moduli of subpanels in Web 2.
IBUCK1	Array of buckling indicators for subpanels in Web 1. Zero indicates that the subpanel has not yet buckled, 1 indicates that the subpanel has buckled.
IBUCK2	Array of buckling indicators for subpanels in Web 2.
ICIB	Counter which is incremented by 1 each time the value of curvature is incremented.
IFLAG	Indicator for long or short output.
IN	Input tape number.
IOUT	Output tape number.
ISTO1A	Array which contains values of array IBUCK1 as they existed for the pre-previous value of curvature.

ISTO2A	Array which contains values of array IBUCK2 as they existed for the pre-previous value of curvature.
ISTO1B	Array which contains values of array IBUCK1 as they existed for the previous value of curvature.
ISTO2B	Array which contains values of array IBUCK2 as they existed for the previous value of curvature.
IULT1	Array of ultimate shear strength indicators of subpanels of Web 1. Zero indicates that the subpanel has not yet reached its ultimate shear strength; 1 indicates that the subpanel has reached its ultimate shear strength.
IULT2	Array of ultimate shear strength indicators of subpanels of Web 2.
NC	Number of longitudinal stiffeners in compression flange.
NDIR	Indicator of the location of the flange stiffeners. -1 indicates that the stiffeners are on the outside of section; 1 indicates that they are on the inside.
NPC	Number of points which define axial load deformation response of a compression flange stiffener beam-column.
NT	Number of longitudinal stiffeners in tension flange.
NW	Number of subpanels in each web.
NW1	Number of subpanels in each web, plus one.
NW2	Number of subpanels in each web, minus one.
PCOMP	Array of normalized stresses describing axial load response of a stiffener beam-column of compression flange (average stress divided by yield stress of compression flange plate). In computations within the program, the values are dimensionalized to forces.
POISSO	Poisson's ratio.
RNCPO	Number of stiffeners in compression flange, plus one.
RNTPO	Number of stiffeners in tension flange, plus one.
S1	Array of three values of strain at corner 1 of section.
S2	Array of three values of strain at corner 2 of section.
S3	Array of three values of strain at corner 3 of section.

S4	Array of three values of strain at corner 4 of section.
SAV1B	Array which contains values of array SUB1B as they existed during the previous increment of curvature.
SAV2B	Array which contains values of array SUB2B as they existed during the previous increment of curvature.
SAVSH1	Array of shear stresses present in subpanels of Web 1 for the previous increment of curvature.
SAVSH2	Array of shear stresses present in subpanels of Web 2 for the previous increment of curvature.
SHEAR1	Array of shear stresses present in bottom subpanel of Web 1 for the values of curvature for which the proper load response has been found.
SHEAR2	Array of shear stresses present in bottom subpanel of Web 2 for the values of curvature for which the proper load response has been found.
SIGYC	Yield stress of compression flange plate.
SIGYST	Yield stress of stiffeners in webs and tension flange.
SIGYT	Yield stress of tension flange plate.
SIGYWB	Yield stress of web plate.
STRA1	Array of strains at corner 1 for curvature values for which the proper load response has been found.
STRA2	Array of strains at corner 2 for curvature values for which the proper load response has been found.
STRA3	Array of strains at corner 3 for curvature values for which the proper load response has been found.
STRA4	Array of strains at corner 4 for curvature values for which the proper load response has been found.
STRNW1	Array of strains at compression flange, web stiffeners, and tension flange, along Web 1.
STRNW2	Array of strains at compression flange, web stiffeners, and tension flange, along Web 2.
SUB1B	Array of bending moments of subpanels of Web 1.
SUB2B	Array of bending moments of subpanels of Web 2.

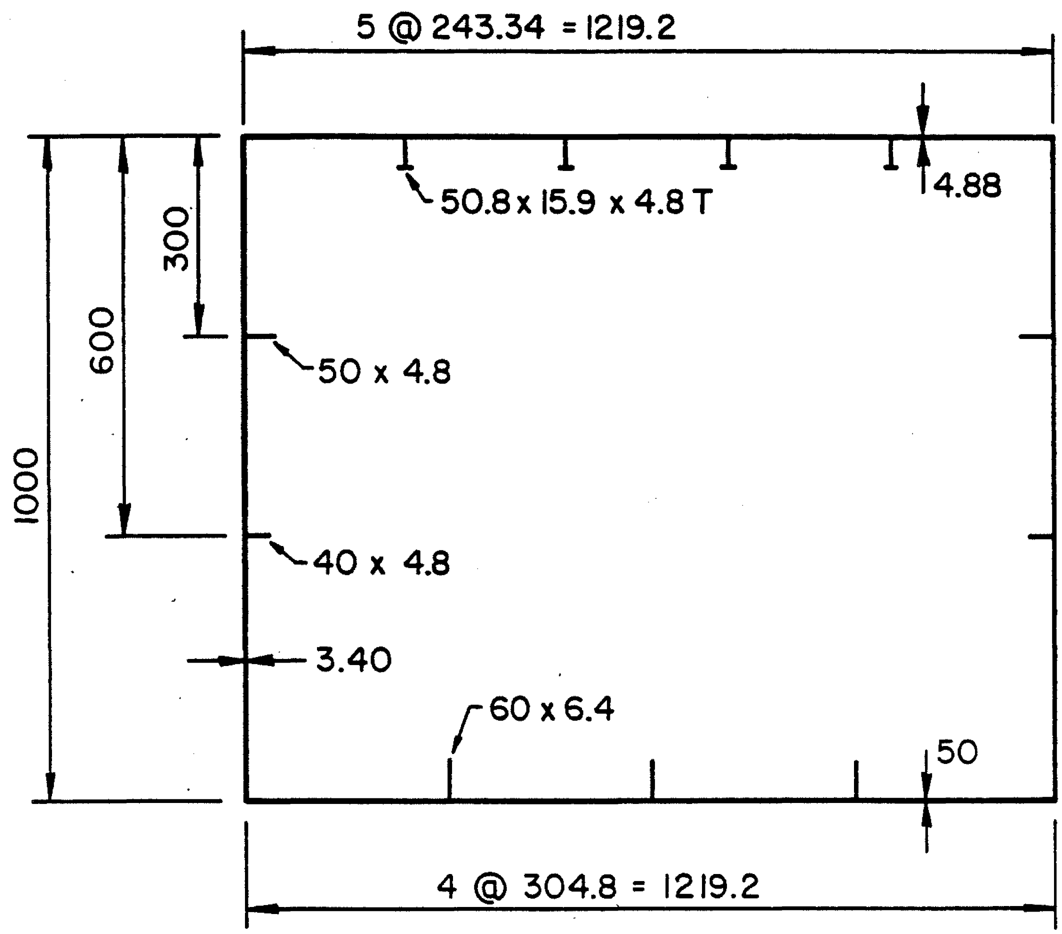
SUB1F	Array of forces of subpanels of Web 1.
SUB2F	Array of forces of subpanels of Web 2.
SUB1SB	Array of shear forces present in subpanels of Web 1 when they buckle.
SUB2SB	Array of shear forces present in subpanels of Web 2 when they buckle.
SUB1V	Array of shear forces carried by subpanels in Web 1.
SUB2V	Array of shear forces carried by subpanels in Web 2.
SUMMA1	Total shear force carried by Web 1.
SUMMA2	Total shear force carried by Web 2.
SWP	Degree of warping (see Fig.2).
TC	Thickness of compression flange plate.
TOLAXF	Tolerance requirement for convergence of axial force.
TOLYBM	Tolerance requirement for convergence of moment about vertical centroidal axis.
TT	Thickness of tension flange plate.
TW	Thickness of web plate.
V1	Array of cross-sectional areas of unbuckled web subpanels multiplied by shear modulus (G).
V1ULT	Array of ultimate shear forces of subpanels in Web 1.
V2ULT	Array of ultimate shear forces of subpanels in Web 2.
VMAX1	Largest shear force carried by Web 1.
VT1	Total shear force carried by web 1.
VT2	Total shear force carried by web 2.
VMAX2	Largest shear force carried by Web 2.
W1FOR	Array of forces in stiffeners of Web 1.
W2FOR	Array of forces in stiffeners of Web 2.
WIN1A	Array which contains values of array WINTR1 as they existed for the pre-previous value of curvature.

WIN2A	Array which contains values of array WINTR2 as they existed for the pre-previous value of curvature.
WIN1B	Array which contains values of array WINTR1 as they existed for the previous value of curvature.
WIN2B	Array which contains values of array WINTR2 as they existed for the previous value of curvature.
WINSAV	Array of buckling interaction values for subpanels of both webs.
WINTR1	Array of buckling interaction values for subpanels of Web 1.
WINTR2	Array of buckling interaction values for subpanels of Web 2.
WLO	Array of calculated load parameters for increments of curvature.
WLOD	Load parameter.
YBMO	Bending moment about the vertical centroidal axis of the section.
YBMOY	Approximate bending moment about vertical centroidal axis which causes yielding of the section.
YS1	Array of strains at corner 1 of the section.
YS2	Array of strains at corner 2 of the section.

5. EXAMPLE

The following cross section is analyzed to illustrate the application of the computer program.

Note: units of length (mm)
units of force (N)
units of stress (MPa)



SIGYC = 298.0
SIGYT = 298.0
SIGYWB = 211.6
SIGYST = 276.5

Length of segment = 787.4
Modulus of Elasticity = 210000.0
Poisson's Ratio = 0.3

Loading condition:

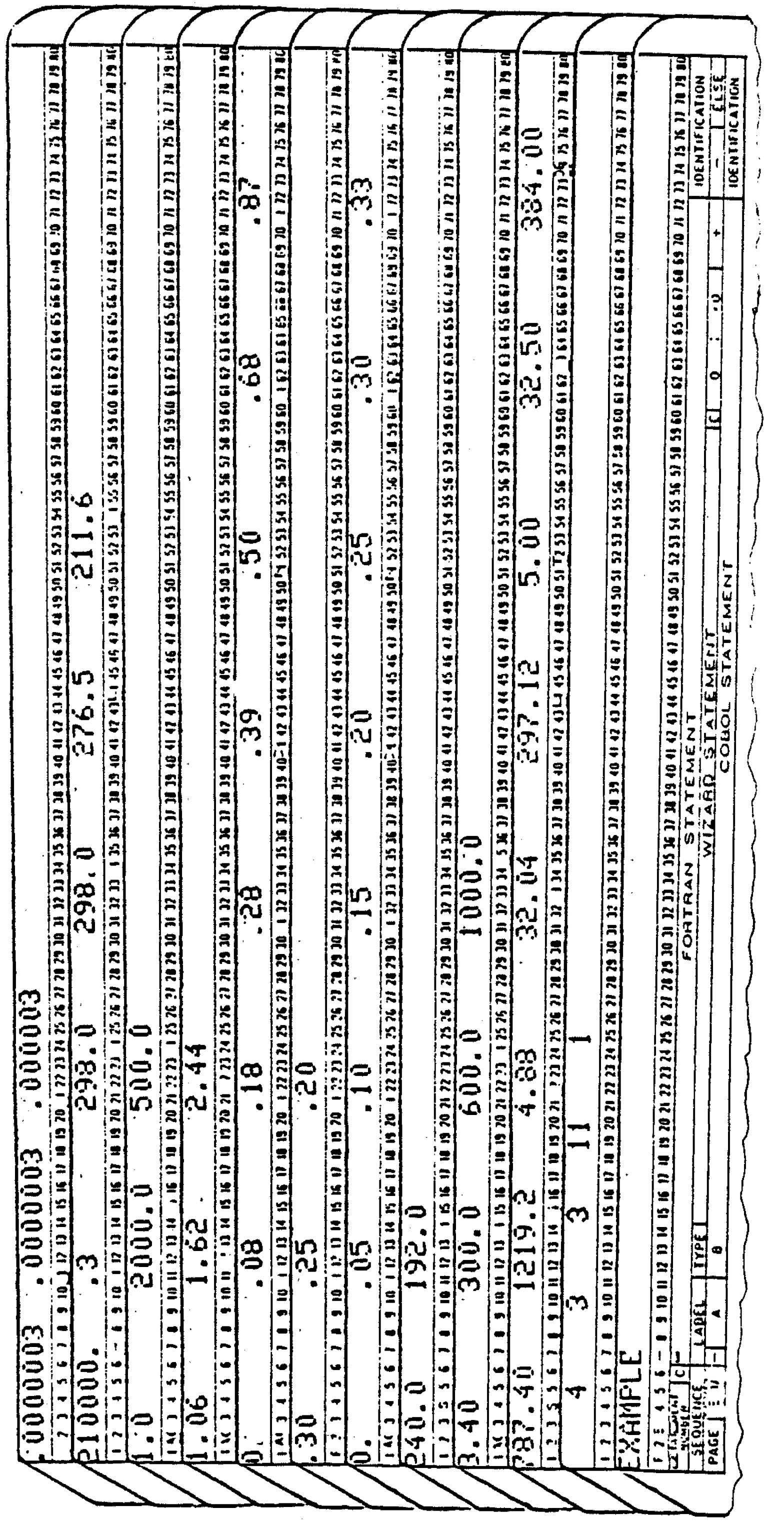
M=2000*V
T=500*V

V=AMU1*W
M=AMU2*W
T=AMU3*W

For example, by setting V=W
AMU1=1.0
AMU2=2000.0
AMU3=500.0

The computer program is capable of producing two different output forms: brief output and detailed output. The complete brief output form is shown in Section 5.1 The detailed output form consists of the brief output plus information about each value of curvature for which the corresponding load parameter was found. A portion of the detailed output, the part corresponding to a curvature of 0.167638E-05 rad/mm, and an explanation are shown in Section 5.2.

The following data cards were used to produce the brief output:



5.1 Listing of Brief Output

```
EXAMPLE
SWP= 0.


DATA READBACK

NC=      4
NT=      3
NW=      3
NPC=     11
NDIR=      1

AA=   .787400E+03
B=  .121920E+04
TC=   .488000E+01
DC=   .320400E+02
AFLSTC=   .297120E+03
TT=   .500000E+01
DT=   .325000E+02
AFLSTT=   .384000E+03

TW=   .340000E+01
D=  .300000E+03
D=  .600000E+03
D=  .100000E+04
D=

ASTW=   .240000E+03
ASTW=   .192000E+03
ASTW=
```

Listing of Brief Output (continued)

```
PCOMP= 0.                   EPPLC= 0.
PCOMP=  .500000E-01         EPPLC=  .800000E-01
PCOMP=  .100000E+00         EPPLC=  .180000E+00
PCOMP=  .150000E+00         EPPLC=  .290000E+00
PCOMP=  .200000E+00         EPPLC=  .390000E+00
PCOMP=  .250000E+00         EPPLC=  .500000E+00
PCOMP=  .300000E+00         EPPLC=  .680000E+00
PCOMP=  .330000E+00         EPPLC=  .970000E+00
PCOMP=  .300000E+00         EPPLC=  .106000E+01
PCOMP=  .250000E+00         EPPLC=  .162000E+01
PCOMP=  .200000E+00         EPPLC=  .244000E+01
PCOMP=

EL=  .210000E+06
POISSO=  .300000E+00
SIGYC=  .298000E+03
SIGYT=  .298000E+03
SIGYST=  .276500E+03
SIGYWB=  .211600E+03

AMU1=  .100000E+01
AMU2=  .200000E+04
AMU3=  .500000E+03
CE=  .300000E-06
CEINC=  .300000E-06
CEMAX=  .300000E-05
```

Listing of Brief Output (continued)

CURVE	W LOAD	S1	S2	S3	S4
.300000E-06	.103915E+06	-.172210E-03	-.172210E-03	.127790E-03	.127790E-03
.600000E-06	.199598E+06	-.351902E-03	-.351902E-03	.249099E-03	.249099E-03
.751440E-06	.247652E+06	-.442228E-03	-.442211E-03	.309229E-03	.309212E-03
.958104E-06	.305994E+06	-.585873E-03	-.562944E-03	.395160E-03	.372231E-03
.107638E-05	.336552E+06	-.664410E-03	-.641464E-03	.434913E-03	.411967E-03
.137638E-05	.402019E+06	-.890222E-03	-.842042E-03	.534335E-03	.496156E-03
.167639E-05	.447432E+06	-.114343E-02	-.105682E-02	.619552E-03	.532946E-03
.180284E-05	.462989E+06	-.126007E-02	-.114882E-02	.654016E-03	.542766E-03
.190483E-05	.467821E+06	-.135827E-02	-.123289E-02	.671940E-03	.546564E-03
.220483E-05	.440270E+06	-.171194E-02	-.152043E-02	.684400E-03	.492995E-03
.250493E-05	.427240E+06	-.203535E-02	-.180013E-02	.704705E-03	.469498E-03
.280483E-05	.418818E+06	-.236720E-02	-.206779E-02	.737039E-03	.437631E-03
.310483E-05	.409000E+06	-.270978E-02	-.233364E-02	.771198E-03	.395050E-03

5.2 Partial Listing of Detailed Output

1

S1	S2	AXF
-.890222E-03	-.842042E-03	.577024E+06
-.890222E-03	-.935285E-03	.434066E+06
-.964378E-03	-.935285E-03	.359399E+06

2

YS1	YS2	YBMO/FACMAG
-.890222E-03	-.842042E-03	-.169704E+06
-.890222E-03	-.935285E-03	-.401420E+05
-.964378E-03	-.935285E-03	-.777736E+05

3

ST1	ST2	ST3	ST4	AXF	YBMO/FACMAG
-.113899E-02	-.105503E-02	.621349E-03	.537389E-03	.712192E+04	-.238432E+03

4

S1	S2	AXF
-.113899E-02	-.105503E-02	.712192E+04
-.890222E-03	-.935285E-03	.434066E+06
-.964378E-03	-.935285E-03	.359399E+06

5

YS1	YS2	YBMO/FACMAG
-.113899E-02	-.105503E-02	-.238432E+03
-.890222E-03	-.935285E-03	-.401420E+05
-.964378E-03	-.935285E-03	-.777736E+05

6

ST1	ST2	ST3	ST4	AXF	YBMO/FACMAG
-.114343E-02	-.105682E-02	.619552E-03	.532946E-03	.153533E+03	.653799E+02

7

ST1	ST2	ST3	ST4	BMO	CURV
-.114343E-02	-.105682E-02	.619552E-03	.532946E-03	.894865E+09	.167638E-05

Partial Listing of Detailed Output (continued)

(8)

GAMMA1= .218858E-02 GAMMA2= .531577E-03

(9)

SUB1F	SUB1B
-.705815E+05	-.120719E+07
-.385646E+05	-.172920E+07
.602274E+05	-.524124E+07

(10)

SUB2F	SUB2B
-.897988E+05	-.153919E+07
-.647859E+05	-.269310E+07
.811894E+05	-.638364E+07

(11)

VT1= .315463E+06 VT2= .131969E+06

(12)

WEB 1	INTERACTION	SHEAR FORCE
	.121092E+01	.711997E+05
	.120075E+01	.906797E+05
	.125478E+01	.153584E+06

(13)

WEB 2	INTERACTION	SHEAR FORCE
	.101430E+01	.297837E+05
	.901303E+00	.437937E+05
	-.665823E+00	.583917E+05

(14)

WEB 1	WEB 2
1	1
1	0
1	0

Description of Items on Pages 27 and 28

1. Three sets of strains with corresponding values of axial force for use by TWOPLA.
2. Three sets of strains with corresponding values of bending moment about the vertical centroidal axis for use by TWOPLA.
3. A better set of strains that were extrapolated by TWOPLA plus the corresponding strains at corners 3 and 4, the corresponding axial force, and the corresponding bending moment about the vertical centroidal axis.
4. Same as Item 1 except that the set of strains which gave the worst value of axial force was replaced with the better set of strains.
5. Same as item 2 except that the set of strains which gave the worst value of bending moment about the vertical centroidal axis was replaced with the better set.
6. A better set of strains which was extrapolated by TWOPLA, similar to Item 3.
7. The same set of strains as Item 6 with the corresponding value of bending moment about the horizontal axis and the value of curvature for this set of iterations. This set of strains gives resultant axial force and bending moment about the vertical centroidal axis which are near zero (within tolerance).
8. Shearing strains in Webs 1 and 2, respectively.
9. Normal force and bending moment in each subpanel of Web 1. The upper-most values of force and moment correspond to the top subpanel of Web 1 and the lower-most values correspond to the bottom web subpanel.

10. Similar to Item 9, but for Web 2.

11. Total shear force in Webs 1 and 2 respectivly.

12. Buckling interaction values and the shearing force in each subpanel of Web 1.

13. Similar to Item 12, but for Web 2.

14. Buckling indicators for the subpanels of Webs 1 and 2. "1" indicates that buckling has occured and "0" indicates that the subpanel has not yet buckled.

6. REFERENCES

1. Ostapenko, A. and Moore, T., ``Maximum Strength of Ship Hulls Subjected to Moment, Torque and Shear,'' Fritz Engineering Laboratory Report No. 479.5 (MARAD Report No. MA-RD-940-82080), Lehigh University, November 1982.

2. Rutledge, D.R., and Ostapenko, A., ``Ultimate Strength of Longitudinally Stiffened Plate Panels (Large and Small b/t, General Material Properties),'' Fritz Engineering Laboratory Report No. 248.24, Lehigh University, 1968.

3. Ostapenko, A., and Vaucher, A., ``Ultimate Strength of Ship Hull Girders under Moment, Shear and Torque,'' Fritz Engineering Laboratory Report No. 453.6 (MARAD Report MA-RD-940-80077), Lehigh University, July 1980.

4. Ostapenko, A. and Surahman, A., ``Structural Element Models for Hull Strength Analysis,'' Fritz Engineering Laboratory Report No. 480.6, Lehigh University, September 1982.

7. ACKNOWLEDGEMENTS

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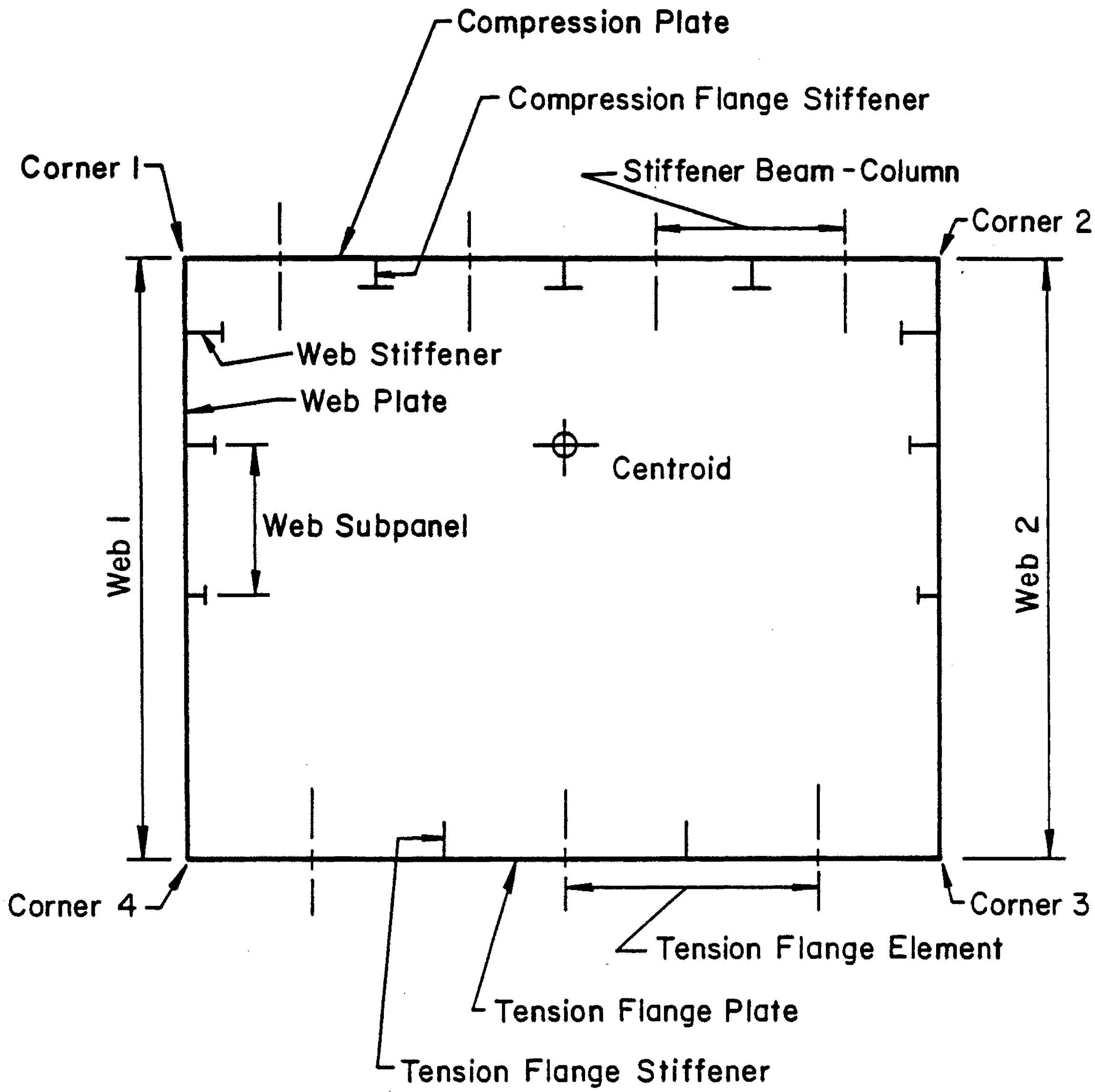
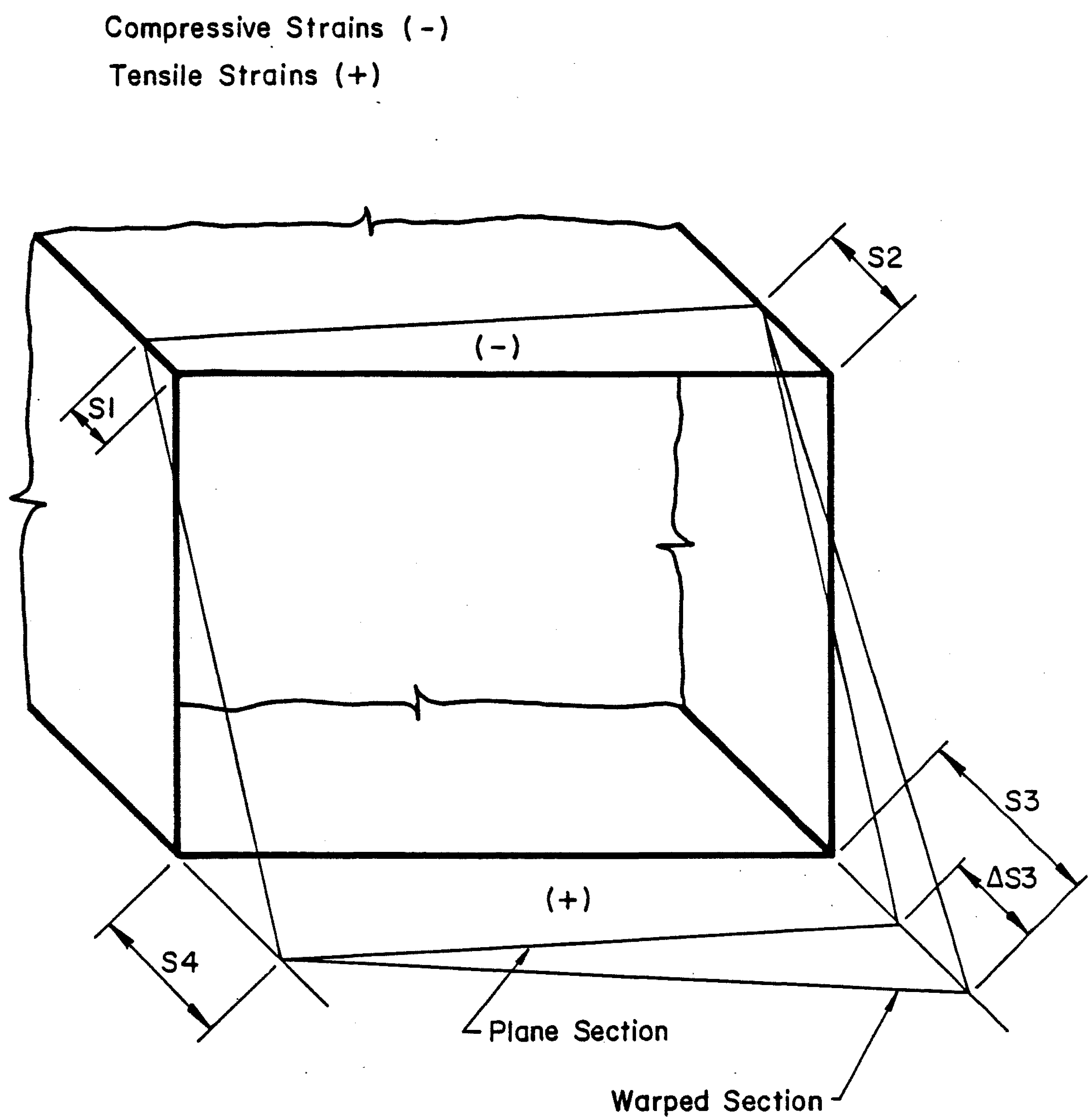


Fig.1 DEFINITION OF COMPONENTS IN CROSS SECTION



Degree of Warping

$$SWP = \frac{\Delta S3}{2(S4 - S1)}$$

Fig.2 STRAIN DISTRIBUTION AND DEFINITION OF WARPING

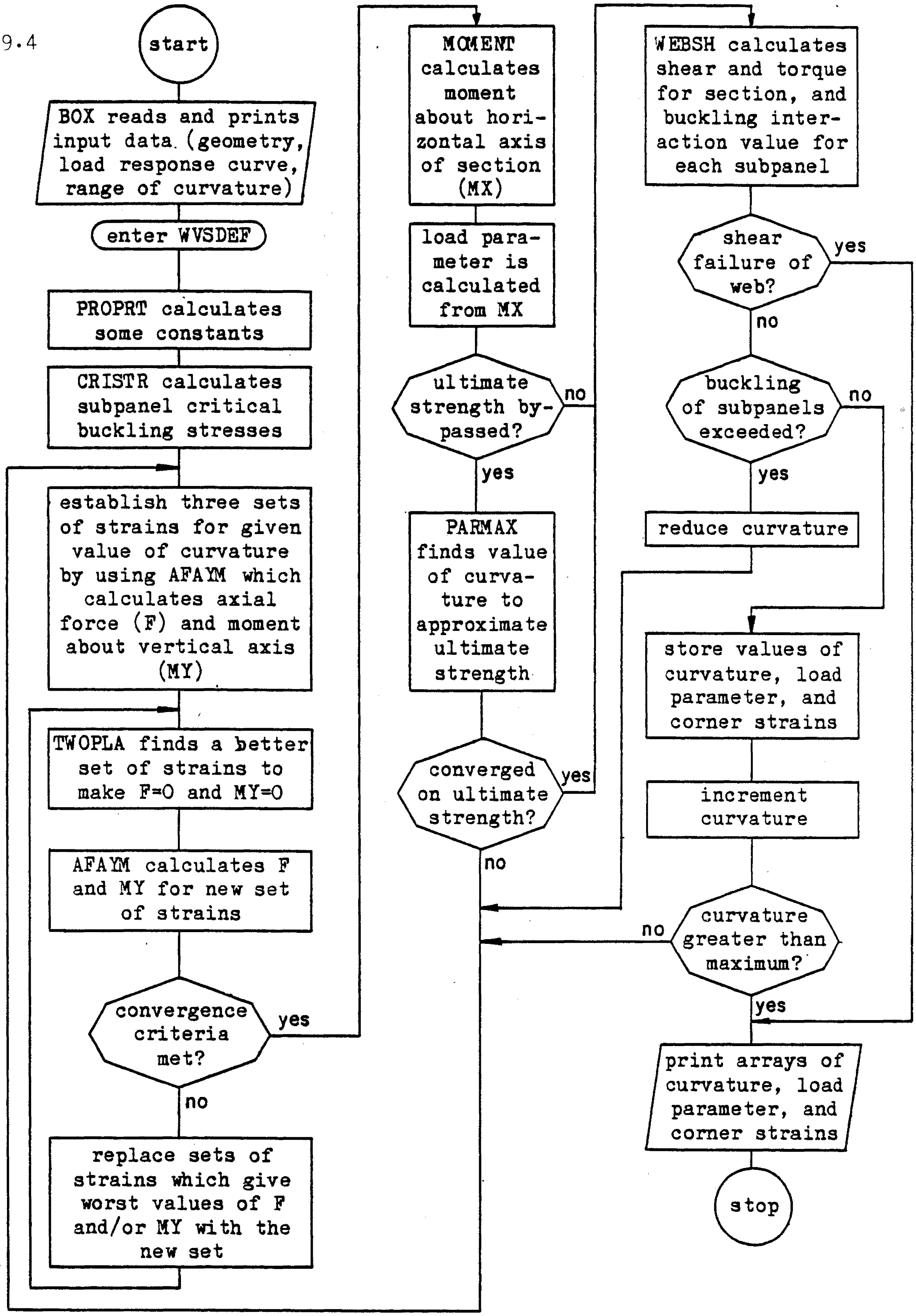


Fig.3 GENERAL FLOW CHART

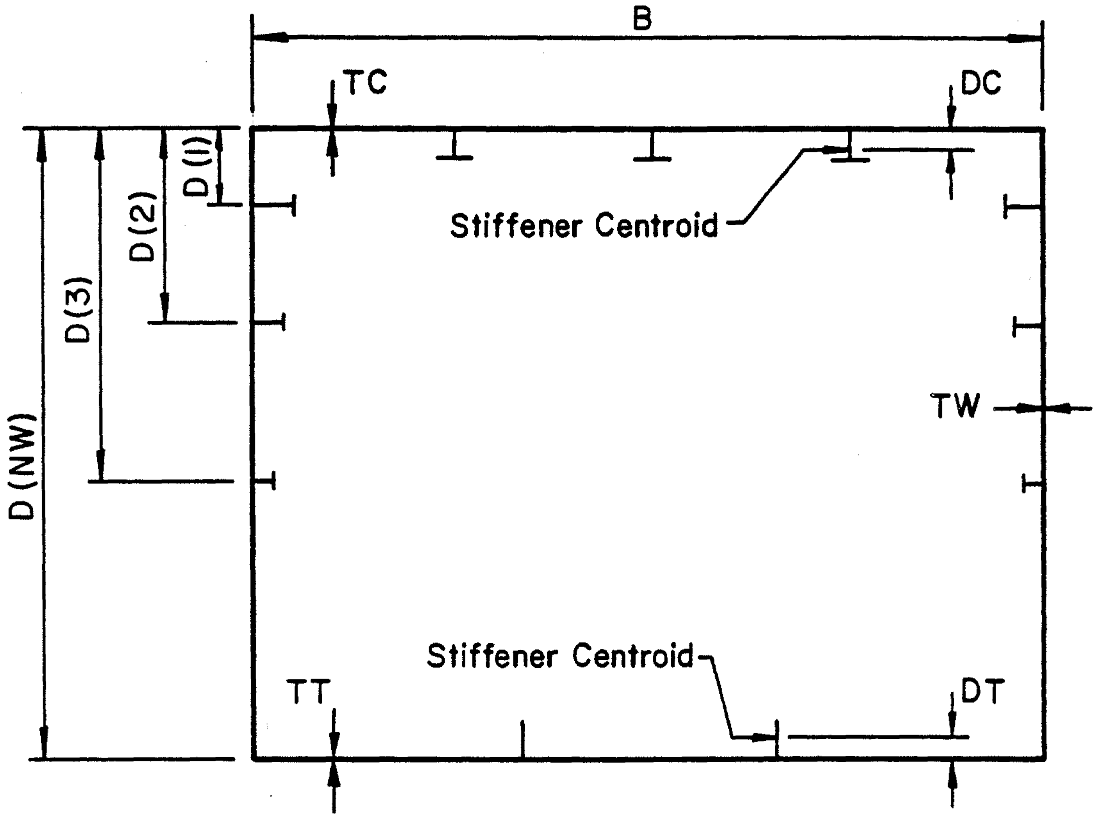


Fig.4 DEFINITION OF CROSS-SECTIONAL VARIABLES